GUNDRILL

CROSS-REFERENCE TO RELATED APPLICATIONS

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This application claims the benefit of U.S. provisional application Serial No. 60/425,478, filed November 11, 2002.

10   BACKGROUND OF THE INVENTION

1.   Field of the Invention

This invention relates to gundrills, i.e., self-
15   piloting drills provided with an internal drilling fluid passage for drilling holes that are quite deep relative to their diameter.

2.   Background Art
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Gundrills are commonly used to drill deep holes into metal components, wherein the hole depth greatly exceeds the hole diameter. Gundrills are widely used in a number of industry applications, such as engine
25   manufacturing, heat exchangers, machine tools, or the like. These applications commonly require deep holes or bores, formed in metal workpieces, by a machining operation. Gundrills are used in applications characterized by holes that are sufficiently deep such that a normal twist drill
30   having two or more cutting edges extending generally outward from a central axis would not work effectively. When drilling relatively deep holes, twist drills tend to wander away or diverge from a central drilling axis, and the flutes tend to clog with metal chips.

In comparison, a gundrill typically has a single cutting edge eccentrically oriented off of the drill centerline. Typically, it is necessary to use a starting bushing or pilot hole to prevent the drill from orbiting off

5   center as the hole is started. Once the hole is initially formed, the drill tip axially guides itself. Gundrills are typically provided with an elongate axial drilling fluid passageway which extends through the drill shank and drill tip. Drilling fluid or coolant is pumped through the

10   drilling fluid passageway and as chips are formed, they are removed from the hole in a stream of drilling fluid in another passageway formed between the hole internal diameter and an elongate groove or flute formed in the gundrill.

Over the years, a number of tip geometries have

15   been utilized in an effort to optimize a drill's performance. In spite of the years of development efforts, there remains a need for an improved gundrill design which can drill holes in a variety of metal workpieces from relatively brittle cast iron to soft ductile aluminum. The

20   gundrill ideally, should be capable of efficiently forming small chips at the cutting tip, which can be effectively extracted from the hole by the cutting fluid. Manufacturers are always trying to increase drill feed rates while minimizing tip wear. It is desirable to maximize the number

25   of holes that can be formed in an hour and to maximize the number of holes that can be formed before the drill tip needs to be redressed. It is further desirable from a maintenance standpoint to have a single tip design which has a minimum number of planar facets which can be redressed by

30   a standard grinding wheel in a gundrill sharpening station.

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SUMMARY OF THE INVENTION

An object of the invention is to provide a gundrill defined as an elongate tubular member formed of a shank and a tip. The shank and tip each have a fluted cross-section and an internal drilling fluid passage. The shank is driven at a fixed end and has a distal end to which a cutting tip is affixed. The fluid passageway extends through the tubular shank and the cutting tip end terminates in an orifice at the tip end. A tip flute extends axially from the tip end and is aligned with the flute formed in the tubular shank. The flute forms a passage for drilling fluid to exit and carry away chips as they form.

An aspect of the present invention is provided, wherein the flute in the cutting tip defines a secondary flank surface and a generally radially extending primary rake surface. The primary rake surface has a peripheral rake edge generally parallel to the central axis of the drill. The primary rake surface defines a generally radially extending cutting edge at the tip end forming a radially offset point. Preferably, the region of the cutting tip that is behind the primary rake surface and the secondary flank surface, is relieved by applying flank or relief planes. The tip end is formed of a series of adjacent relief surfaces, which are preferably planar facets. A four facet design illustrated has outer relief and inner relief, a secondary relief (intermediate the outer/inner relief) and a dub-off relief behind the corner formed by the secondary flank surface and the outer periphery of the tip. These relief surfaces collectively define a tip end surface through which the drilling fluid orifice passes. The tip end cooperates with the bottom of the hole being formed and defines therebetween a bottom

clearance space into which drilling fluid from the orifice initially flows before the bulk of the fluid exits the bottom space through an outlet passage defined between the lowermost edge of the secondary flank surface and the hole bottom.

The present invention controls the relative size of the outlet section in order to optimize drilling fluid flow for chip removal purposes, and for cooling and lubricating of the cutting surfaces and wear paths. The cross-sectional area of the outlet passage can be expressed in the form of a ratio with respect to the bottom space cross-sectional area. The outlet passage area should be less than 100 percent, preferably less than sixty percent and most preferably less than 25 percent of the bottom space cross-sectional area.

In a further aspect of the invention, the cutting tip primary rake surface has a peripheral rake edge, which is generally parallel to the central axis. The region immediately behind the peripheral rake edge deviates inwardly from this cylindrical hole being formed to provide an enlarged circumferentially localized relief passage providing an axial flow path between the outer periphery of the cutting tip and the cylindrical bore of the hole being formed. The relief passage communicates with the bottom space which causes pressurized cutting fluid to flow through the relief passage, cooling and lubricating the peripheral rake edge. Preferably the relief passage is formed by machining a relief flat behind the peripheral rake edge inclined inboard twenty to thirty degrees from a plane which is tangent to the hole being drilled and perpendicular to the primary rake surface. Preferably, over ten percent of the drilling fluid exits the bottom space through the side relief passage.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a side view of a conventional prior art gundrill with a solid carbide tip;

Figure 2 is a cross-sectional view of the gundrill of Figure 1 taken along section line A-A;

Figure 3 is a fragmentary cross-sectional view of the gundrill of Figure 1 taken along section line B-B;

Figure 4 is a fragmentary cross-sectional view of the gundrill of Figure 1 taken along section line E-E;

Figure 5 is a fragmentary cross-sectional view of the gundrill of Figure 1 taken along section line D-D;

Figure 6 is an axial end view of the gundrill of Figure 1;

Figure 7 is an axial end view of another conventional prior art drill bit having a helical convex flank surface, or relief surface, of relatively great generating diameter;

Figure 8 is a partial side view taken in the direction of arrow H_1 in Figure 7;

Figure 9 is an axial end view of a conventional prior art drill bit having a helical convex flank surface, or relief surface, of relatively small generating diameter;

Figure 10 is a partial side view taken in the direction of arrow H_2 of Figure 9;

Figure 11 is a cross-sectional view of a hole being drilled by the drill bit shown in Figure 1;

Figures 11a-11c illustrate three alternative bottom space cross-sections for gundrills designed to cut respetively typical, soft and brittle materials;

Figure 12 is an axial end view of the drill bit of Figure 11;

Figure 13 is a cross-sectional view of the drill bit taken along view line Q2-Q2 of Figure 12;

Figure 14 is a cross-sectional view of the drill bit taken along view line Q1-Q1 of Figure 12;

Figure 15 is a partial side view of a prior art gundrill with a slash tip design;

Figure 16 is a partial side view of a prior art gundrill with a notch outlet tip design;

Figure 17 is a partial side view of a prior art gundrill with a square step tip design;

Figure 18 is a partial side view of a prior art gundrill with a step slash tip design;

Figure 19 illustrates the drilling fluid flow and the stagnation zone occurring in a typical step slash gundrill tip design;

Figure 20 illustrates the drilling fluid flow angle in a typical slash gundrill tip design;

Figure 21 illustrates an enlarged side elevational view of a gundrill tip of the present invention;

Figure 22 is a cross-sectional view taken along section line S-S of Figure 21;

Figure 23 is a cross-sectional view taken along section line R-R in Figure 21;

Figure 24 is a side elevational view taken in the direction of arrow T in Figure 21;

Figure 25 is an axial end view of the gundrill embodiment in Figure 21;

Figure 26 is an axial end view of the gundrill in Figure 21 cooperating within a hole being drilled;

Figure 27 is a cross-sectional view illustrating the gundrill of Figure 26 and the associated hole being drilled;

Figure 28 is a cross-sectional view of a gundrill and associated hole taken along section line U-U of Figure 26;

Figure 29 is a side elevational view of a gundrill of the present invention;

Figure 30 is an enlarged axial end view of the gundrill tip taken in the direction of arrow V;

Figure 31 is an alternative embodiment of the gundrill tip shown in Figure 30;

Figure 32 is an enlarged view of the crossover port taken in the direction of arrow W in Figure 29;

Figure 33 is a cross-sectional view taken along section line X-X of Figure 29;

Figure 34 is a side illustration of a gundrill of the present invention drilling a workpiece illustrating drilling fluid indicia of flow;

Figure 35 is an axial end view taken in the direction of arrow Y in Figure 34; and

Figure 36 is a top view taken in the direction of arrow Z in Figure 34.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

In order to understand the subtle, but dramatic differences between the present invention and the prior art, it is necessary to first understand the gundrills of the prior art, particularly how they interact with the hole being formed and the drilling fluid being supplied to the cutting tip. After a detailed analysis of chip formation and the drilling fluid flow behavior in prior art gundrills, the benefits and advantages of the present invention can be fully understood and appreciated.

Gundrilling is a method of drilling holes where a self-piloting tool with an internal drilling fluid supply and an external chip removal path is used. A commonly used gundrill 100 of the prior art is shown in Figures 1 through 6. Gundrill 100 consists of a drill body having a shank 101 and a tip 102. The tip 102 is mounted on the free end of the shank 101, and is made up of a hard wear-resistant material such as a metallic carbide. The other end of the shank 101 is provided with an enlarged driver 103 having a machine-specific design. The driver 103 mounts to a tool holder on a rotary spindle of a drilling machine and is supplied with pressurized drilling fluid.

The shank 101 is tubular having an elongated internal passage 104 (Figure 2) extending within its entire length and connecting to the drilling fluid supply passage 105 in the tool holder. The shank 101 has a generally V-shaped flute 106 on its exterior surface. The flute 106 terminates in an inclined, ramp or crease 107 formed adjacent to the driver 103. The shank wall thickness depends on a particular tube producer. Commonly, it is in the range of ten to twelve percent of the outside diameter of the shank. The angle of the V-flute profile of the shank, Ψ_s is usually between 100 degrees and 130 degrees. The shank length is determined from the tool layout. It depends mainly on the depth of the drilled hole, and the axial length of the starting bushing, its holder and the chip box, if employed.

The shank 101 is smaller in diameter than the tip 102, in order to prevent the shank 101 from contacting the walls of the hole being drilled. Flute 108 in tip 102, which is similar in shape to flute 106 in shank 101, extends along the full length of the tip 102. The flutes 106 and 108 are longitudinally aligned. The above description is

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illustrated in Figure 1 as a straight flute construction, which is preferred for ease in manufacturing the present invention, but other flute constructions such as that of a helical type are also possible.

Tip flute 108 is bounded by sidewalls 109 and 110, which are hereafter referred to as the secondary flank surface and the primary rake surface, respectively (Figure 6). The secondary flank surface 109 is referred to as a flank surface, rather than rake surface because it does not perform a cutting operation upon the workpiece. The depth of this flute 108 is such that primary rake surface 110 extends past the axis 111 (distance b) of the tip portion, which is also the axis of the drill body. The angle between the secondary flank surface and the primary rake surface is known as the profile angle of the tip ψ_v which is usually equal or close to the V-flute profile of the shank, ψ_s. The profile angle is typically between 100 degrees and 130 degrees.

The terminal end of the tip portion is formed with outer 112 and inner 113 cutting edges, having approach cutting edge angles φ_1 and φ_2 respectively. These cutting edges meet at the drill point P. The location of P (defined by distance m_d in Figure 1) can be varied for optimum performance depending on the work material and the finished hole specifications. One common prior art example includes a point that is ground such that the outer angle φ_1 is measured as thirty degrees, from a plane normal to the axis 111 and intersecting point P; and the inner angle φ_2 is measured as twenty degrees. The geometry of the terminal end largely determines the shape of the chips, the effectiveness of the drilling fluid, the lubrication of the tool, and removal of the chips. The process of chip formation is also governed by other cutting parameters such

as the cutting speed, feed rate, work material, and the like.

A primary relief 112a is commonly provided on the flank of the outer cutting edge 112 when steels and alloyed work materials are to be drilled. This relief is illustrated in Figure 3 with a normal clearance, or flank, angle, α_{n1}, which is typically characterized between eight and twelve degrees. In drilling of easily machinable materials, the outer cutting edge 112 is provided with the single relief, or flank surface 112a. A secondary flank or outer flank plane 114 is applied to the outer cutting edge 112 to provide space for the drilling fluid to reach the cutting edge 112 (Figure 3). The secondary flank 114 is illustrated as clearance angle α_{n1-2}, which is approximately twenty degrees. The inner cutting edge 113 includes a flank or inner flank plane 115, with the normal clearance, or flank, angle equal to α_{n2}, which is normally between eight to twelve degrees (Figure 4).

Figures 4 through 6 depict a gundrill having planar flank, or relief, surfaces. The outer flank plane 114 lies adjacent to the outer cutting edge 112. The inner flank plane 115 lies adjacent to the inner cutting edge 113 and intersects the outer flank plane 114 at point P. An auxiliary flank plane 116 is applied between the outer and inner flank planes 114 and 115, to prevent possible interference of the rib (shown in Figure 6 by a phantom line) which forms as the intersection line after outer and inner flank planes 114 and 115 are ground. The auxiliary flank plane 116 is normally ground with a flank angle α_{n3} within a range of twenty-five to thirty-five degrees (Figure 5). A shoulder dub-off plane 117 is located as shown in Figures 1, 4, and 6. Normally, the shoulder dub-off angle, shown in Figures 1, is equal to thirty degrees to assure

free penetration of point C (Figures 4 and 6) in drilling.

Normally, the fluid passage 104 terminates at a tip orifice 118, that is located on the inner flank plane 115 (Figure 6). Gundrill manufacturers have adopted various shapes for this orifice; one or two circular holes or a single crescent, comma-like or kidney-shaped hole.

Another common prior art shape of the flank, or relief, surface is a helical surface rather than a planar surface. The helical flank surface is normally applied to the flank of the outer cutting edge. Different manufacturers have different standards on the lead and generating diameter of the helical flank surface, depending upon drill diameter. Modern designs use great lead and generating diameters so that the flank surface of the outer cutting edge does not affect the shape of the flank plane of the inner cutting edge, or the shoulder dub-off.

For example, with reference to Figure 7, a helical convex surface 119 is applied to an outer cutting edge 120. The lead and generating diameters of this surface are relatively large so the line, or rib of intersection 121 of outer 119 and inner 122 flank surfaces does not extend too far from the vertical axis 123. Therefore, shoulder dub-off 124 is not affected by the helical surface 119 such that a line of intersection 126 of a secondary flank surface 125 and the shoulder dub-off 124 is a straight line having a shoulder dub-off angle φ4 as illustrated in Figure 8.

In older designs, for example US Patent No. 2,325,535, which are still in use, a relatively small lead and generating diameter of the helix surface is used so that this surface passes through the outer flank and shoulder dub-off as shown in Figure 9. In this figure, a helical convex surface 127 is applied to an outer cutting edge 128. This helical convex surface 127 has a small lead and

generating diameter so that it passes through a flank surface 129 of an inner cutting edge 130. As such, the line of intersection of the secondary flank surface 131 and the flanks 129 and 127 is a jagged line consisting of two lines 132 and 133 (Figure 10). The shoulder dub-off angle in this prior art illustration is shown in Figure 10.

Figures 11 through 14 depict a gundrill while drilling. The rotation of an outer cutting edge 134 and an inner cutting edge 135 about a longitudinal central axis 136 results in the formation of a sculpture surface 137 upon the bottom region of the hole being drilled. The shape of this surface is uniquely determined by the shape and location of the cutting edges and location of the drill point P (parameter m_d in Figure 1). Therefore, the space occupied by this surface, which is referred to as the bottom space, is uniquely determined by these design parameters. Important for our further considerations is the axial cross-sectional area of the bottom space which is the area limited by polygon $ABCDE$ shown in Figure 11. For example, for the common design of gundrill design shown in Fig. 1 where the outer and the inner cutting edges are straight, the axial cross-sectional area of the bottom surface is calculated by:

$$A_{BS} = \left[(R_d - m_d)^2 \tan \varphi_1 + m_d^2 \tan \varphi_2 \right] + 2 m_d \left[(R_d - m_d) \tan \varphi_1 + m_d \tan \varphi_2 \right] \qquad (1)$$

wherein R_d is the drill radius (Figure 6); m_d is the location distance of the drill point P (Fig. 1); φ_1 is the approach cutting edge angle of the outer cutting edge; and φ_2 is the approach cutting edge angle of the inner cutting edge (Figure 1).

Between the sculpture surface 137 of the hole being drilled, and opposing outer flank 138, auxiliary flank 139, and inner flank 140, of the drill, a limited clearance

space 141 provided. The complicated topology of the bottom clearance space 141 can be appreciated in different cross-sections. One such cross-section is shown in Figure 14, wherein a narrow amount clearance is provided between the outer flank 138 and the sculpture surface 137.

The drilling fluid is supplied into the bottom clearance 141 under pressure through a drilling fluid passage tip orifice 144. The drilling fluid pressure in the bottom clearance space 141 has a major influence on the cooling and lubrication condition on the inner flank 140, outer flank 138 and the respective cutting edges as well as on a pair supporting pads, 145, 146. The supporting pads 145 and 146 extend longitudinally along the gundrill for contacting the inner diameter of the hole and piloting the drill therein.

As an increased drilling fluid pressure is applied, the life of the drill is extended. High drilling fluid pressure provided in the bottom clearance space 141 provides better penetration of the drilling fluid to the extremely narrow passages (see SECTION Q1-Q1 in Figure 14), thus enhancing the lubricating and cooling of the flank contact areas. This is particularly important for drilling fluid penetration in the regions adjacent to the drill periphery point B (Figure 11) due to the highest radial speed and the removal of the greatest material volume of the workpiece. Unfortunately, the prior art does not adequately supply drilling fluid to this area; and, therefore, the tool wear in this region is much higher then in other regions.

It is a common belief that the drilling fluid pressure in the bottom clearance space 141 can be increased by increasing the inlet drilling fluid pressure, Pm. This belief is flawed. In prior art gundrill designs, an increase in the inlet pressure results in a corresponding

increase in the drilling fluid flow rate. The increased
fluid flow rate causes an increase in hydraulic resistance
within the drilling fluid supply channels such that the
drilling fluid pressure in the bottom clearance space 141
5   does not rise proportionally relative to the increased fluid
flow rate.

Hydraulic resistance within the bottom clearance
space 141 increases significantly as the fluid flow rate is
increased in prior art gundrill designs. The velocity of the
10   drilling fluid jet as it exits the tip orifice 144 (Figure
12), increases significantly with the increased flow rate.
Pressure losses occur when this fluid jet contacts the
sculpture surface 137. These pressure losses are in effect,
a loss of energy, thus causing a release of additional heat.
15   Consequently, the increased drilling fluid pressure causes
an increase in temperature, instead of decreasing it.

High drilling fluid velocities in the bottom
clearance space 141, combined with low static drilling fluid
pressure may lead to drilling fluid cavitation. A liquid
20   boils at the temperature at which the surrounding pressure
is equal to the vapor pressure. Thus, if a liquid flows
into a region wherein the pressure is equal to its vapor
pressure at that temperature, it boils forming vapor
pockets, collectively referred to as fluid cavitation.
25   Effects of cavitation are most noticeable in regions of high
localized velocities. When even 'minor' cavitation occurs,
the cooling ability of the drilling fluid reduces
dramatically such that the tool life of the gundrill is
further decreased.
30   The proper way to calculate the drilling fluid
pressure p_{BC} in the bottom clearance space 141 is as follows:

$$p_{BC} = \gamma_c (h_{DO} + h_v) \tag{2}$$

wherein γ_c is the specific weight of the drilling fluid, in
Newtons per meter cubed (N/m^3); h_{DO} is the hydraulic
resistance of the side drilling fluid passage formed by a
shoulder dub-off surface 147 and the sculpture surface 137,
in meters (m); and h_v is the hydraulic resistance of the V-
flute, in meters (m).

The hydraulic resistance of the V-flute, h_v is very
small compared to the hydraulic resistance h_{DO}; therefore,
Equation (2) can be rewritten as:

$$p_{BC} = \gamma_c h_{DO} \tag{3}$$

As seen from this equation, under a given flow rate, the
drilling fluid pressure in the bottom clearance space 141 is
fully determined by the hydraulic resistance of a side
drilling fluid passage, hereinafter referred as the side
passage 148, which forms between the shoulder dub-off flank
147 and the sculpture surface 137 of the hole being drilled.
The longitudinal cross-sectional area of the side passage
148 has a direct impact on the hydraulic resistance. This
area is best depicted in cross-section Q2-Q2 (Figure 13) as
enclosed by polygon $C_1C_2C_3C_4C_5$.

There are several widely recognized drill bits
designs having various arrangements of the shoulder dub-off
surfaces, commonly referred to as: a slash gundrill (Figure
15), a slash with a notch gundrill (Figure 16), a square
stepped gundrill (Figure 17) and a stepped-slash gundrill
(Figure 18). These designs differ significantly in the
outlet cross-sectional area of the side passage 148.

The slash, or general purpose, gundrill (Figure
15) is the most common design for European made drills,
however some Japanese and North American manufacturers also

utilize similar designs. The slash gundrill is the preferred design used today because it provides the maximum resistance of the side passage 148, in comparison to other existing designs, and consequently the maximum drilling fluid pressure in the bottom clearance space 141. This maximum drilling fluid pressure is caused by the relatively small cross-sectional area of the side passage 148 generated by the shoulder dub-off surface 149 being located sufficiently proximate to a sculpture surface 150 of the hole being drilled.

In the simplified common slash gundrill (Figure 15), the outer and inner cutting edges 134 and 135 are straight. As such, this side passage area is calculated as:

$$A_{ot-sl} = 0.5\left\{A_{BS} + \left(\sqrt{R_d^2 - b^2 \sin^2 \psi_v} + b \cos \psi_v\right)^2 \left(\tan \varphi_4 - 2 \tan \xi_L\right)\right\}$$

(4)

wherein φ_4 is the shoulder dub-off angle, the measurement of distance b is illustrated in Figure 6, and

$$\xi_L = \arctan \frac{\left(R_d - m_d\right)\tan \varphi_1 - (m_d + b)\tan \varphi_2}{b \cos \psi_v + \sqrt{R_d^2 - b^2 \sin^2 \psi_v}}$$

(5)

To increase the drilling fluid flow rate under a given pressure and thus to assure reliable chip removal, a notch 151 was added on the shoulder dub-off surface 149 as shown in Figure 16. The drilling fluid pressure in the bottom clearance space 141, however, becomes smaller because the cross-sectional area of the side passage 148 increases.

In the notched gundrill depicted in Figure 16, the outer and inner cutting edges 134 and 135 are straight, so the area of the side passage 148 is calculated as:

$$A_{ot-sl-n} = A_{ot-sl} + A_n \tag{6}$$

wherein A_{ot-sl} is provided by equation 4; and A_n is the cross-
sectional area of the notch.

Initially, these prior art notched gundrill
designs were introduced when gundrills were used on old or
retrofitted machines, which were not capable to deliver high
drilling fluid pressure.

The stepped square gundrill (Figure 17) and the
stepped slash gundrill (Figure 18) designs provide a cross-
sectional area of the outlet section of the side passage
that is relatively large. In the stepped square design, a
side passage 152 is formed without a shoulder dub-off
surface. Instead, a drill flat flank face 153 is spaced
from the distal end in the axial direction. A sculpture
surface 154 and the flat flank face 153 form the step shown
in Figure 17. In the simplified stepped square gundrill,
the outer and inner cutting edges 134 and 135 are straight,
and consequently the cross-sectional area of the side
passage 152 is calculated as:

$$A_{ot-sl} = R_d S_t + 0.5 A_{BS} \tag{7}$$

wherein S_t is the length of the step (Figure 17); and A_{BS} is
the axial cross-sectional area of the bottom space which is
calculated using Equation 1.

In the stepped slash design shown in Figure 18, a
shoulder dub-off 155 is provided rather than the flat flank
face 153 of the square stepped design. In a simplified
example, the outer and inner cutting edges 134 and 135 are
straight, such that the cross-sectional area of the side
passage 152 is calculated as:

$$A_{ot-st} = R_d S_t + 0.5\left(A_{BS} + R_d^2 \tan\varphi_4\right) \tag{8}$$

wherein φ_4 is the shoulder dub-off angle.

5   Although modern gundrilling machines are capable to deliver high drilling fluid pressure, the stepped-slash design is still in wide use today, particularly in the automotive industry.

    The stepped square and the stepped-slash designs
10 were introduced by a gundrill manufacturer that had limited knowledge of gundrilling. Although the intent behind these designs was to increase the flow rate through gundrills and thus improve chip removal, the application of these designs improved only apparent flow rate (fixed by a flow meter
15 installed on the machine). With these designs, the drilling fluid static pressure in the bottom clearance space is very low. As a result, the drilling fluid does not have sufficient static pressure to flow in the narrow passages adjacent to the flank of the outer cutting edge 134 (see
20 Figure 14). Insufficient static pressure results in reduced tool life.

    Another drawback of the prior art gundrills is not readily apparent to gundrill manufacturers and users. The chip removal process can be characterized as consisting of
25 two stages, namely, chip collection, or pick up, and chip transportation along the V-flute chip removal groove. The latter requires sufficient drilling fluid flow rate and its reliability increases with this flow rate. The former is difficult to perceive and analyze and therefore, is commonly
30 misunderstood during the design of gundrills.

    Chip pick up is defined as the initial drilling fluid-chip interaction, resulting in collection of chips

that are formed at the cutting edges, and picked up by the drilling fluid flow from the outlet cross section of the side cutting edge. Accordingly, as the drilling fluid exits the outlet cross-section of the side cutting edge, the fluid

5   interacts with chips that are formed on the rake face adjacent to the outer and inner cutting edges 134 and 135. The chips become entrained in the drilling fluid flow and thus their normal transportation is possible.

When a gundrill having the stepped-slash design is

10   employed, the fluid flow is schematically illustrated in Figure 19. The drilling fluid, as referenced by arrows and numeral 156, is supplied in the bottom clearance space 141, and impacts a sculpture surface 157 of the hole being drilled, and is subsequently reflected by the sculpture

15   surface 157 into the V-flute. A majority of the deflected drilling fluid 158 does not flow to the cutting edge because it is merely reflected and exited. As illustrated in Figure 19, the fluid 156 'misses' the machining zone. Chips formed by outer cutting edge 159 and inner cutting edge 160 are not

20   readily entrained in the fluid flow, and a 'dead' or stagnation zone 161 is formed.

Multiple studies indicate that chip collection may be regulated to an angle β with respect to a longitudinal axis 163 of the drill, which represents the drilling fluid

25   flow direction as it enters the V-flute from a side passage 162 (Figure 20). The chip collection effectiveness improves as β is increased. When the angle β is less than sixty degrees, a stagnation zone forms on the tool rake face and the chips may experience difficulties in joining the

30   drilling fluid flow. A stagnation zone is created wherein angle β for the stepped design is approximately sixty-five degrees; and for the stepped-slash design, angle β is less than forty-five degrees. This relationship explains why

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chip plugs can form in the V-flute in the proximity of the
cutting edges, although the overall flow rate is very high.

By carefully analyzing the results of conducted
studies with the various tip designs, the effect and
5   importance of outlet cross-sectional area is better
understood. Table 1 below summarizes the comparison of the
various prior art tip designs for an 8mm diameter gundrill
wherein the only parameter variance is the machining of the
relief region of the tip defining the shape of the outlet
10   passage. The various designs are ranked by the cross-
sectional area of the outlet section in an effort to develop
design parameters that are useful. A design parameter for
various diameter drills and bit angles is dictated by
varying materials to be drilled.

15

TABLE 1

Comparison of the cross-sectional area of the outlet passage of the side passages and drilling fluid pressure in the bottom clearance space for different known designs.

Gundrill parameters: diameter $D = 8mm$ (0.315"), $R_d = 5mm$, $m_d = 2mm$, $b=0.5mm$, $\varphi_1=30°$, $\varphi_2=20°$, $\alpha_{n2}=12°$, $\psi_v=120°$, $\varphi_4=30°$. For slash design with a notch: $A_n=2.5mm^2$. For the stepped design: $S_t=3mm$, $\varphi_4=0°$. For the stepped-slash design: $S_t=3mm$, $\varphi_4=30°$. Drilling fluid flow rate is 5 Gpm (18.74 l/min).

Design	Cross-sectional area of the outlet section of the side passage, A_{ot}, mm^2	Axial cross-sectional area of the bottom space, A_{BS}, mm^2	Bottom Space Ratio A_{ot}/A_{BS}	Static Drilling fluid pressure in the bottom clearance space, Mpa
Slash	6.32	5.64	112%	0.15
Slash with a notch	8.82	5.64	156%	0.10
Stepped	14.82	5.64	263%	0.04
Stepped-slash	24.06	5.64	423%	0.01

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Another important parameter is the cross-sectional area of the outlet which is evaluated as a ratio of this area to the bottom space area. This parameter is referred to as bottom space ratio. Static drilling fluid pressure in the bottom space is compared for the various designs.

Controlling the area of the outlet passage by careful tip design and the relief variant enables one having ordinary skill in the art to greatly improve chip removal and tip cooling. Traditionally, large outlet passage areas were believed to be variable in that they allowed for a greater drilling fluid flow. However, it has been determined that the absolute volume of drilling fluid flow is unimportant if the drilling fluid design does not adequately cool the active cutting surfaces of the tip or if stagnant pockets form in the region of the drill point.

The gundrill of the present design carefully controls the machining of the relief portion of the tip to maintain a relatively small outlet passage area, this results in a relatively high static drilling fluid pressure in the bottom clearance space. The increased pressure of the fluid in the bottom clearance space enables, through careful tip design, the fluid to be directed where it is needed most to cool the cutting edges, thus eliminating stagnation pockets. Sufficient flow is maintained to still effectively remove chips from the hole being drilled through the elongate fluid return path formed by the tip and shank flutes.

Figures 21-28 illustrate the tip geometry of cutting tip 200 of a preferred embodiment of the invention. It should be appreciated that the specific geometry of the cutting tip practicing the present invention may vary dramatically, as a function of drill diameter and the hardness of the material drilled and its chip formation

properties. The gundrill cutting tip 200 is preferably formed of a carbide material that is brazed or welded to the drill shank. The cutting tip 200 is illustrated in side elevation in Figure 21 viewing the cutting tip generally

5   normal to primary rake surface 202. Primary rake surface 202 in conjunction with a secondary flank surface 204 form a generally V-shape tip flute 206 having an included angle of approximate 100 degrees to 130 degrees and preferably 120 degrees. The tip flute 206 is generally aligned with a

10   corresponding shank flute in the associated elongate tubular shank to provide a passageway within the bore of the hole being drilled for chips and cutting fluid to be removed.

The cutting tip 200 is provided with an internal fluid passage 208 which terminates in an orifice 210. The

15   plane of the primary rake surface 202 is recessed slightly relative to drill centerline 212 as illustrated in Figures 21 and 25. Secondary flank surface 204 is likewise slightly recessed relative to a radial plane extending through the drill centerline 212.

20   The primary rake surface 202 is provided with a radial outboard peripheral rake edge 214 which lies on a cylindrical surface coaxial with central axis 212. In the preferred embodiment illustrated, the peripheral rake edge 214 forms a line lying on the plane of the primary rake

25   surface 202 and is parallel to centerline 212. The tip of the primary rake surface 202 terminates in a radial offset point 216 offset a distance m_d from centerline 212. Point 216 is defined by outer cutting edge 218 and inner cutting edge 220. Outer cutting edge 218 forms an angle φ_1, which in

30   the illustrative embodiment is about twenty-five degrees. The inner cutting edge 220 forms an angle φ_2 which is approximately seventeen degrees. As the cutting tip 200 is rotated and axially advanced into the workpiece, the outer

cutting edge 218 and inner cutting edge 220, along with a portion of the peripheral rake edge 214 adjacent the outer cutting edge 218, axially cut the workpiece forming chips.

The angles φ_1 and φ_2, of cutting edges 218 and 220, as previously indicated are in a large part dependent upon the hardness and chip forming characteristics of the material being drilled. As illustrated in Figure 11b, when the material is soft, the outer/inner cutting edge angles will increase. When the material is brittle as illustrated in Figure 11c, the outer/inner cutting edge angles will be reduced significantly relative to a cutting tip design for typical materials shown in Figure 11a. Once the tip profile and cutting edges are defined, the remaining surfaces formed on the cutting tip end are then designed to be recessed sufficiently to provide clearance as the gundrill is rotated and axially advanced and to direct the flow of drilling fluid.

In the embodiment illustrated, cutting tip 200 has its end defined by four generally flat machined surfaces or facets. In use, gundrills are frequently sharpened requiring the facets forming the tip to be periodically re-ground. It is, therefore, desirable to have a relatively few number of facets which are easily machined on a tool sharpening station. While the preferred embodiment illustrated utilizes four facets, a five or six facet design can alternatively be used. Similarly, while the present design utilizes four planar facets, it is possible to substitute a frusto conical or helical facet as shown in the prior art gundrills in Figures 17 and 19. The purpose of the machined facets on the end of the cutting tip is to properly define the point 216 and outer 218 and inner 220 cutting edges, while providing adequate clearance, maintaining structural support for the cutting edges, and

controlling the area of an outlet passage 222. The outlet
passage 222 is illustrated in Figure 28 which connects the
bottom clearance space with the internal fluid passageway
formed between the tip flute 206 and the circumferentially

5   bored holed through which cutting fluid and chips, as they
are formed, exit.

In the embodiment illustrated, the four facets
machined on the end of the cutting tip are outer relief
surface 224, inner relief surface 226, auxiliary relief

10   surface 228, and dub-off relief surface 230. The primary
relief angle α_{n3} in the embodiment illustrated is
approximately twenty degrees as illustrated in Figure 22
which is a section taken along section line S-S in Figure
21. In the embodiment illustrated, inner relief surface 226

15   forms a twelve degree relief angle α_{n2} as shown in Figure 24
when viewed in the direction of arrow T in Figure 21. The
auxiliary relief surface 228 forms an angle α_{n1-2} of
approximately twenty-five degrees as shown in Figure 23 when
viewed in cross-section R-R in Figure 21. The dub-off

20   relief surface 230 forms an angle φ_4 approximately equal to
the approach angle φ_1 of the outer cutting edge as
illustrated in Figure 24 when viewed the direction of arrow
T in Figure 21. The dub-off relief surface 230 is
particularly important. This machined surface is primarily

25   responsible for determining the physical size of the outlet
passage 222 formed between the cutting tip 200 and the hole
being drilled. The outlet passage area is calculated
utilizing a solid modeling computer design program, which
not only considers the tip geometry, but the axial feed rate

30   of the gundrill. Considering feed rates is particularly
important when soft materials are being cut and the axial
feed rate is very high.

The amount of relief provided by the inner relief surface 226 and auxiliary relief surface 228 dictates the volume of the bottom clearance space between the end of the cutting tip 200 and the sculpture surface of the hole bottom. The bottom clearance space must be sufficiently large so as to not obstruct the flow of the drilling fluid through orifice 210. To further enhance drilling fluid flow through orifice 210, a sharp corner of the orifice formed at the intersection of the internal fluid passageway 208 and the inner relief surface 226 is radiused slightly, initially and after each tip sharpening operation. By controlling the area of outlet passage 222, the bottom clearance space will be maintained at a substantial pressure which enables the drilling fluid flow exiting the bottom clearance space to be controlled by tip geometry. The largest flow path for fluid exiting the bottom clearance space is outlet passage 222. By controlling the outlet passage 222 size, the angle of the jet of fluid exiting the outlet passage 222, β may be maximized. Angle β is the largest angle formed by the cutting fluid as it exits the outlet passage 222, and before it begins upward to exit the hole. Angle β is illustrated in Figure 27. Angle β is best measured experimentally by machining a clear plastic block and visually observing the angle from the bottom as it exits orifice 222. Ideally, β will be as large as possible while still maintaining adequate drilling fluid flow sufficient to remove chips from the hole being formed. In order to prevent stagnation, angle β should be greater than sixty-six degrees. Ideally angle β will be greater than seventy-five degrees and most preferably, angle β will be greater than eighty degrees in order to direct drilling fluid into the cutting region and to prevent stagnation.

Since the geometry of the cutting tip 200 of the present invention varies significantly as a function of hole diameter and material, the outlet passage 222 area can be best expressed as a function of the longitudinal cross-sectional area of the bottom space taken along the central axis 212. The bottom space cross-sections for various material hardnesses are illustrated in Figures 11a, 11b and 11c. It should be appreciated that frequently the hole diameter and the longitudinal cross-section of the bottom space can vary dramatically. Brittle materials require a relatively flat drill tip resulting in a small longitudinal cross-section of the bottom space, while soft materials as illustrated in Figure 11b have a much larger bottom space cross-section. The outlet passage 222 area will increase or decrease accordingly as a function of the bottom space longitudinal cross-section. The outlet passage 222 area should be always maintained less than the longitudinal cross-section of the bottom space. Preferably, the outlet passage is less than seventy-five percent of the bottom space cross-section, and most preferably, less than half of the bottom space cross-sectional area. By carefully controlling the tip geometry and the axial feed range, the outlet passage 222 area is less than twenty-five percent of the longitudinal cross-sectional area of the bottom space when practicing the present invention in applications where tip cooling is a problem.

By controlling the outlet passage 222 area, not only can the orientation of the fluid flow exiting the outlet passage 222, be controlled to maximize β, but the resulting increase in the static drilling fluid pressure in the bottom clearance space can further provide the ability to direct fluid about the cutting tip 200 circumferential periphery as the hole is formed. As a result of maintaining

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relatively high fluid pressure in the bottom clearance
space, it becomes possible to direct drilling fluid from the
bottom clearance space to areas of the cutting tip 200,
which experience wear or cooling problems. Such a region is
5   the peripheral rake edge 214 which frequently experiences
wear near the corner formed by the outer cutting edge 218
and peripheral rake edge 214. To cool this region, the
gundrill cutting tip 200 of the present invention is
provided with a localized relief passage 232 which extends
10   between the cutting tip and the hole being formed in the
area immediately circumferentially behind the advancing
peripheral rake edge 214. Relief passage 232 is formed by
machining away material from the cutting tip 200 while
forming a localized flat, or alternatively, a concave
15   depression running axially along the cutting tip immediately
behind peripheral rake edge 214. The machined relief
passage 232 preferably extends the length of the cutting tip
providing an alternative exit path for cooling within the
bottom clearance space.
20   After the localized relief passage 232 extends the
length of the cutting tip 200, it is connected to the
internal fluid passage formed in the flute, by crossover
port 236 illustrated in Figures 29, 32, 34 and 36.
Crossover port 236 can alternatively be machined in the
25   cutting tip 200, in the end of the shank, or partially in
both the cutting tip 200 and the shank. The crossover port
236 is oriented relative to the elongate fluid return path
to introduce a jet of drilling fluid at an angle which
assists the drilling fluid and the entrained chips to exit
30   the hole being drilled.
               Ideally, the outlet passage 222 is sized to be
sufficiently small in relation to the relief passage 232 so
that over ten percent of the drilling fluid that is

delivered to the orifice 210 exits the end clearance volume through the relief passage 232. Preferably, more than fifteen percent of the drilling fluid exits the end clearance volume through the relief passage 232. In gundrills which have historically experienced cooling and wear problems in the region of the peripheral rake edge 214, the outlet passage 222 can be sized sufficiently small so that over twenty percent of the drilling fluid exits the end clearance volume through the relief passage 232.

Figure 29 illustrates a gundrill 240 made in accordance with present invention. The gundrill 240 consists of a shank portion 242 and a tip portion 244. The shank portion 242 is preferably formed of hard material, such as hardened steel. The shank portion 242 may be formed from a thick wall tubular member which has a diameter slightly undersized relative to that of the cutting tip portion 244, to assure maximum torsional and bending rigidity which is particularly important when drilling deep holes. Shank portion 242, is formed from tube stock, by swedging or deforming the tube to form a generally longitudinally extending V-shape flute 246. Flute 246 serves to form a chip removal passage in cooperation with the internal surface of the hole being drilled. Normally, flute 246 extends for a substantial portion of the shank length and terminates at an incline ramp 248 which is generally adjacent driver 250 to which the fixed end of the shank 242 is attached.

Driver 250 is adapted to connect to the spindle chuck on the drilling machine and will have a complimentary profile suitable for attachment with the chuck to be used. The driver 250 is further provided with a drilling fluid inlet port which can be coupled to a source of high pressure drilling fluid in the drilling station. Drilling fluid

flows through the internal passage in the driver 250 through an internal fluid passage 252 which extends through shank 242 and through the internal fluid passage 254 extending through the tip 244 which terminates at orifice 256.

5   Cutting tip 244 is generally bounded by an imaginary cylinder corresponding to the size of the hole being drilled which is slightly larger in diameter than the maximum diameter of shank portion 242. Shank flute 246 is generally V-shaped and extends the full length of cutting

10   tip 244. The cutting tip 244 is secured to the end of the shank 242 by a braze or weld in a conventional manner so that tip flute 258 is generally aligned with the shank flute 246. In the embodiment illustrated, tip flute 258 and shank flute 246 are shown as straight. While this construction is

15   preferred, it should be understood that if desired, the flutes which form an elongate fluid return path can extend helically about the cutting tip 244 and shank 242. The cutting tip flute 258 is generally bounded by primary rake surface 260 and secondary flank surface 262. As previously

20   described in the preferred embodiment, the free end of the cutting tip forms a cutting point 264 formed by outer cutting edge 266 and inner cutting edge 268. This simple design facilitates easy re-sharpening as the machined facets, which form the cutting surfaces on the end of the

25   cutting tip become worn and used. It should be understood, of course, that if desired, the designer can form a primary rake surface 260 with a series of axially extending flats or an axially extending concave curve while still practicing the present invention. However, planar primary rake and

30   secondary flank surfaces are preferred for simplicity, ease of manufacture and ease of re-sharpening.

          Gundrill 240 has its outer generally cylindrical wall portion shaped to provide a pair of raised narrow axial

elongate wear pads 270 and 272, which are spaced about the
periphery of the cutting tip 244 and extend longitudinally.
Wear pads 270 and 272 are raised slightly relative to the
adjacent cylindrical surface of the cutting tip 244 in order
5   to limit the contact of the hole being drilled since the
cylindrical portion of the cutting tip 244 to the two wear
pads 270, 272 and peripheral rake edge 274 all lie on this
cylindrical surface. Since cutting point 264 is offset from
the drill centerline, the reaction force caused by the
10   cutting of the material to be removed causes the cutting tip
244 to be urged radially, the reaction force caused by
forming the hole being drilled is transmitted by wear pads
270 and 272. Of course, it is possible to have fewer or
more than two wear pads; however, the simple dual wear pad
15   design is commonly used and is preferred.

              The remainder of the cylindrical portion of the
cutting tip 244 is recessed slightly relative to the two
wear pads and the peripheral rake edge 274, for providing an
axial flow path for drilling fluid to cool and lubricate the
20   cutting tip 244 as the hole is formed. In the preferred
embodiment of the cutting tip 244 illustrated, a large
localized relief passage for drilling fluid is formed in the
region immediately behind the peripheral rake edge 274 as
the drill is rotated in the cutting direction. This
25   localized relief passage is formed by machining material
from the cutting tip 244 in order to depart from the
cylindrical hole being formed in the region intermediate the
peripheral rake edge 274 and the first wear pad 270. Figure
30 illustrates a planar relief surface 276, which is
30   machined into the outer generally cylindrical surface of the
cutting tip behind the peripheral rake edge 274. The planar
relief surface 276, in conjunction with the cylindrical hole

being drilled, defines a generally crescent shape localized relief passage 278 as illustrated in Figure 35.

An alternative relief passage configuration is illustrated in Figure 31. Rather than the planar relief surface 276 as shown in Figure 30, the alternative embodiment is provided with a concave relief surface 280 which enables a slightly larger cross-section relief passage to be formed in a given circumferential area of the cutting tip 244. The size of the planar or concave relief passage 278 should be sufficiently large to enable adequate drilling fluid to flow therethrough to cool the peripheral rake edge 274 as well as the outer cutting edge 266. The size of the relief passage 278 will be in part, dependent upon the size of the outlet passage 222, which is the region bounded by the distal end of the secondary flank surface 228 and the sculpture surface of the hole being drilled (Figure 28). It is desirable that a balance of flow exists between the relief passage 278 and the outlet passage 222 so that the flow of fluid out of the bottom clearance space is carefully controlled.

It is preferred that at least ten percent of the drilling fluid introduced into the end clearance volume is discharged through the relief passage 278; and, more preferably, it is desired that at least fifteen percent of the drilling fluid, which enters the end clearance volume, exits through the relief passage 278. In some applications wherein wear has been experienced at the peripheral rake edge 274 or at the intersection of the peripheral rake edge 274 and the primary rake surface 260, the relative area of the relief passage 278 can be increased so that over twenty percent of the drilling fluid that enters the end clearance volume exits through the relief passage 278.

As previously noted, the remaining cylindrical portion of the cutting tip 244 is either a wear pad 270 or 272, which abuts the hole being drilled, or a region slightly recessed from the hole being drilled to provide a

5 slight clearance. Some very small amount of flow will exit the end clearance space through this recessed region although drilling fluid flow is primarily through the outlet passage 222 and the relief passage 276.

The flow of drilling fluid through relief passage

10 278 ultimately will rejoin the drilling fluid flowing through the internal fluid passageway defined between the shank flute 246 and the wall of the hole being drilled. Relief passage 278 will preferably connect to the shank flute 246 by way of the crossover port 236 illustrated in

15 Figures 32, 34 and 36. The crossover port 236 is configured to introduce a jet of drilling fluid into the tubular shank passageway at an angle which assists the drilling fluid in the entrained chips to exit the hole being drilled. The flow of drilling fluid through the crossover port 236 is

20 illustrated by the directional flow arrows in Figures 34-36. Figure 35 illustrates an alternative orifice 284 having a circular cross-section as opposed to the kidney-shaped cross-section shown previously. In the case of a circular cross-section orifice located within the center of the inner

25 relief face 226 illustrated, the addition of the localized relief passage 278 causes drilling fluid to flow immediately behind the primary cutting and secondary cutting edges 266 and 268, which form the drill cutting point 264. The addition of localized relief passageway 278 significantly

30 reduces the temperature of these cutting surfaces and dramatically increases tool life. The flow of drilling fluid through the localized relief passage 278 also serves to minimize material buildup on the peripheral rake edge

274, which improves the surface quality of the hole being drilled and helps to minimizes the likelihood of chip accumulation in the internal fluid passage 252.

The flow of drilling fluid through the localized relief passage 278 can be experimentally observed by drilling a clear plastic block in the manner that flow rates through outlet passage 222 were observed to experimentally measure angle β. In order to observe the drilling fluid flow, a strobe light was utilized and the flash frequency adjusted so that the drill appeared to rotationally stand still. The flow of drilling fluid through outlet passage 222, through localized relief passage 278, and through crossover port 236 could be visually monitored. While orienting the crossover port 236 in a manner to introduce the flow of drilling fluid through the relief passage 278 into the fluid at an angle, the relief passage 278 flow aided in removing chips from the cutting tip 244 and further prevented chip clogging in the shank flute 246.

While the preceding description focuses primarily on the structure of the gundrill cutting tip it should be appreciated that the present invention further encompasses the method of using of a gundrill having tip geometry which, when rotated and axially advanced relative to the workpiece forms an outlet orifice area measured between the end of the secondary flank and the hole being drilled which is a controlled size relative to the cross-sectional area of the bottom clearance space. The method further controls drilling fluid pressure in the bottom clearance space so that the drilling fluid exits the orifice forming an angle β which is sufficiently large to prevent drilling fluid stagnation. The gundrill tip may be further cooled in a novel manner by forming a relief passageway behind the peripheral rake edge which is sized relative to the orifice

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to allow a significant amount of the drilling fluid entering in the clearance space to exit through the relief passageway. It should be appreciated that the geometry of the cutting tip utilized in the present invention may vary

5   greatly based on hole diameter, material hardness and material chip forming characteristics. Similarly various facet designs can be used to practice the invention. The present invention is not intended to be limited by the preferred embodiments illustrated, as the numerous changes

10   may be made to the tip geometry while still practicing the invention set forth in the following claims.

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